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Experience from Application of a 3D Ice Accretion Code

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Introduction

- Use of 2D analysis codes is well documented.

- 2D codes validated for a relatively large number of applications, but only applicable where 2D flow assumptions are valid.

- Desirable to be able to model complex geometries, including geometrical double curvature.

- 3D code necessary to accurately predict flow, droplet impingement and ice accretion.

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ICECREMO Overview

- Code developed by UK consortium: British Aerospace (now BAe SYSTEMS), Rolls-Royce, GKN Westland Helicopters Ltd and DERA (now QinetiQ). Part funded by the UK Department for Trade and Industry.

- General ice accretion prediction code which can be applied to various problems through appropriate choice of an aerodynamic flow solver.

- Trajectory and icing analysis performed on a prescribed flow solution.

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ICECREMO Overview (2)

- Series of surfaces defined, upon which droplet impingement calculations are made.

- Lagrangian droplet particle tracking under the influence of local flowfield, aerodynamic drag, bouyancy and gravitational weight.

- Freezing model includes water film thickness and allows conduction through ice.


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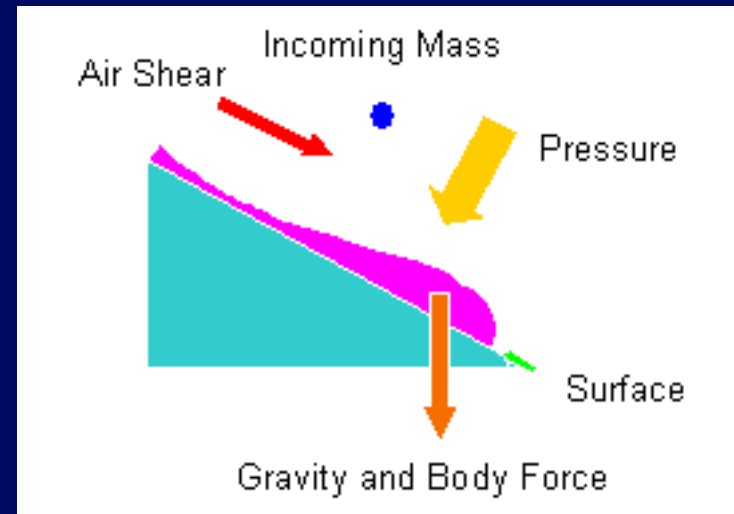
Case Studies

Study 1: An Unmanned Air Vehicle

- Analysis carried out on forward radome and sensor turret of a mission sensor pod of a UAV operated by the UK Army.

- Single block aerodynamic grid extended 5 sensor pod lengths upstream.

- Cross-section sufficient to ensure droplet impingement on radome nose.

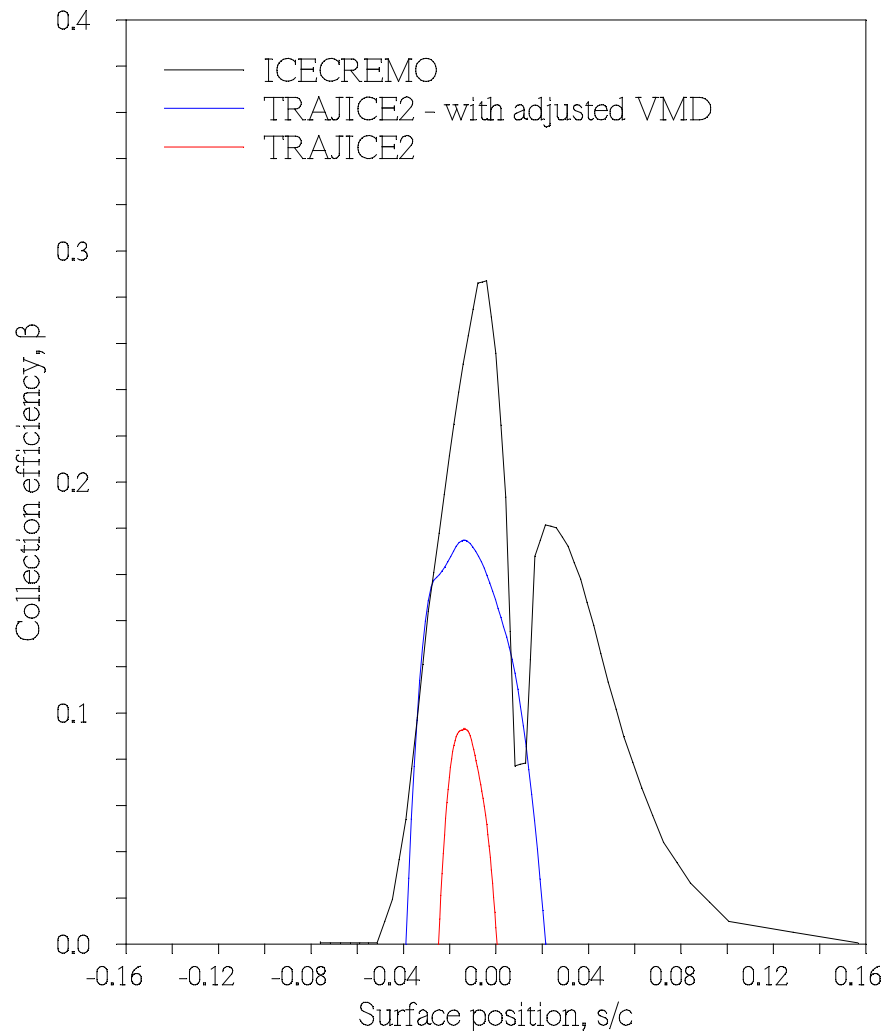

radome

turret

sensor pod

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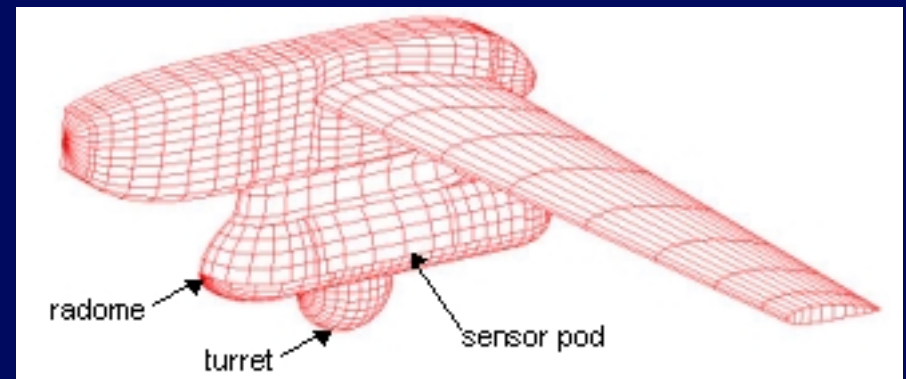
An Unmanned Air Vehicle (2)

- For radome, ice profile tracings taken from vertical station passing through highlight.

- Predicted profile compares well to that measured.

- Predicted aft extent of ice less than measured.

- Differences in fine detail due to assumption of homogeneous ice in prediction.
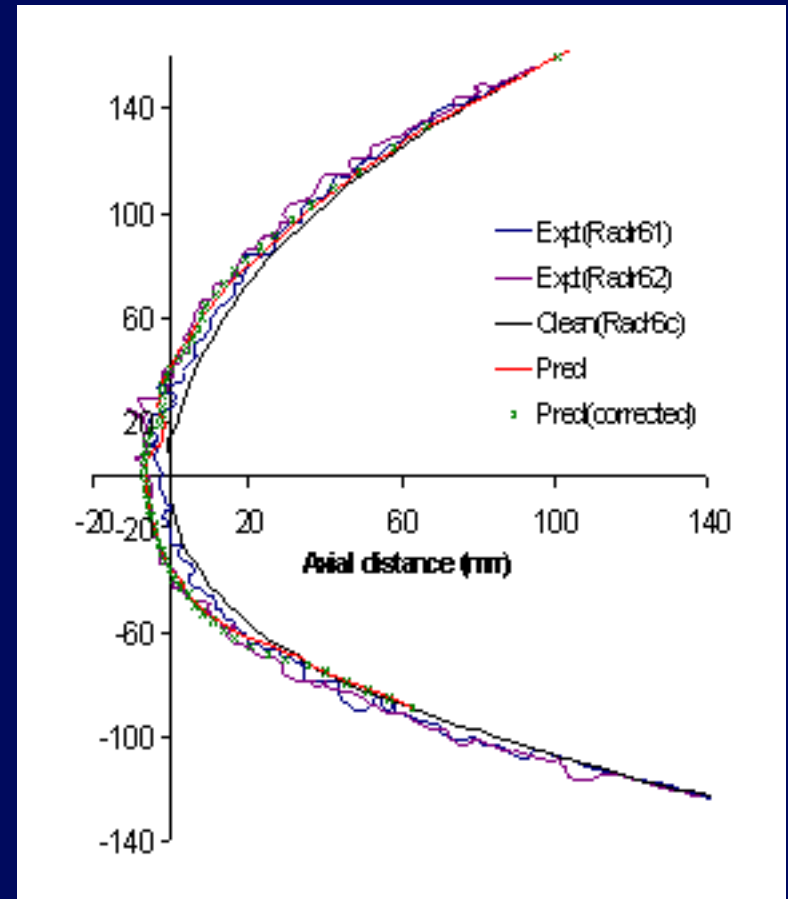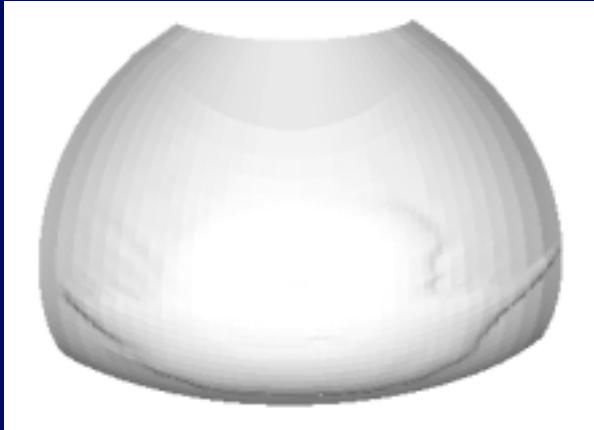
An Unmanned Air Vehicle (3)

- Analysis performed using TRAJICE2 code to compare 2D and 3D prediction.

- Significant difference if 2D approximation made.

- 3D curve not smooth due to insufficient particle numbers.
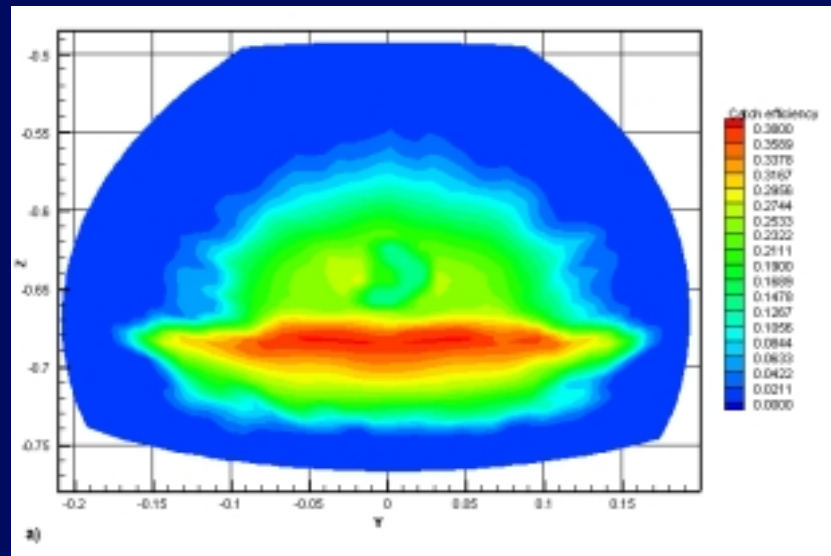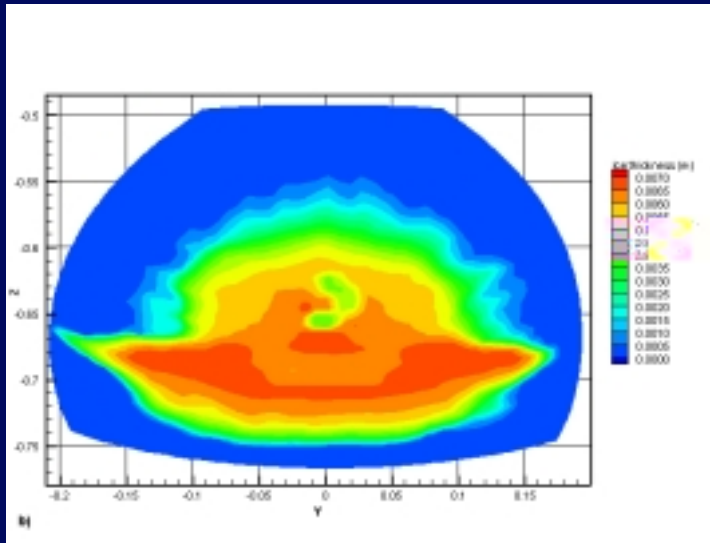
An Unmanned Air Vehicle (4)

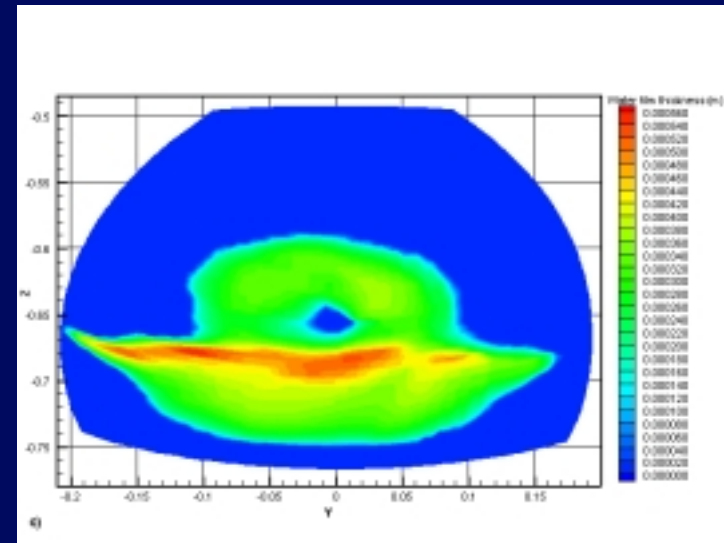
ICECREMO Prediction

Icing tunnel
test result

Predicted collection
efficiency

An Unmanned Air Vehicle (5)

Ice thickness

Water film thickness

Heat transfer coefficient

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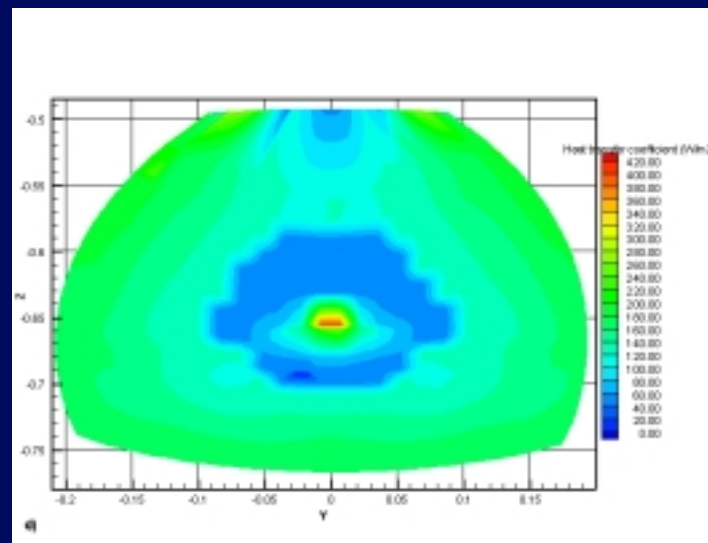
An Unmanned Air Vehicle (6)

- For the sensor turret, analysis predicted a significant shielding effect on the turret by the mission sensor pod.

- 'Dead band' produced where there is no water droplet impact and therefore no ice accretion.

- Wind tunnel tests confirm this result. ICECREMO prediction compares very well to the test result.

radome
turret
sensor pod

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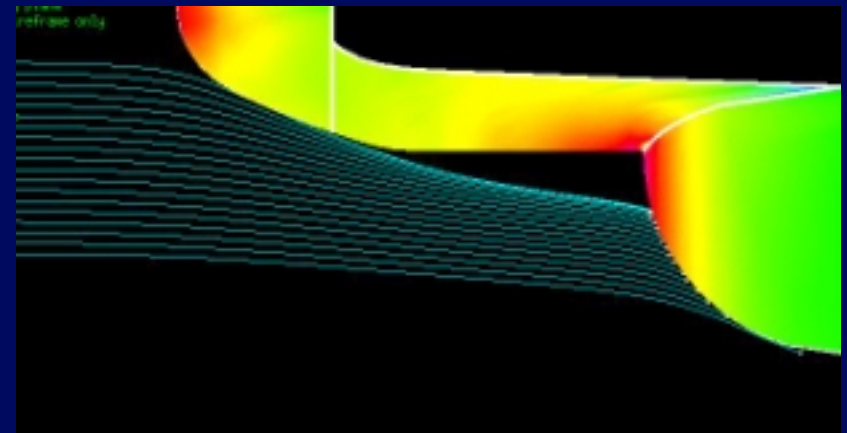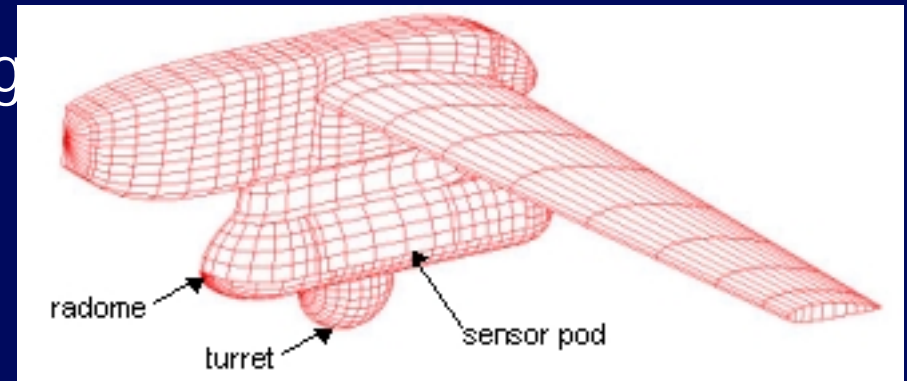
An Unmanned Air Vehicle (7)
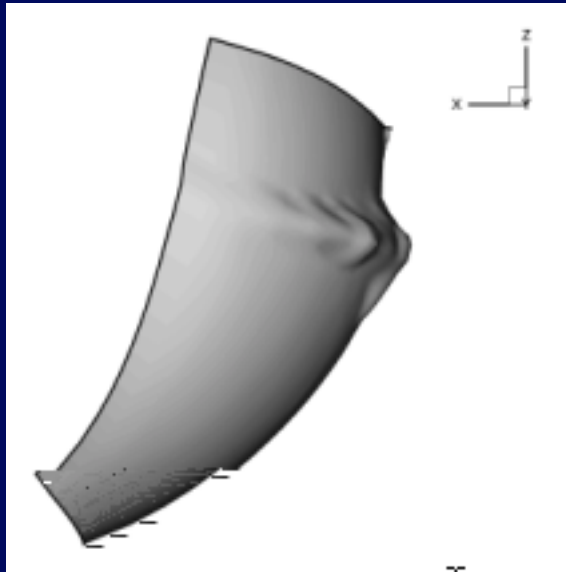
ICECREMO Prediction

BRAIT icing tunnel
test result

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An Unmanned Air Vehicle (8)

Lessons Learned

- Study illustrates the importance of modelling components which affect flow upstream of component of interest.

- Prediction of isolated turret would have produced entirely wrong answers since shielding effects would have been neglected.

- Analysis using 2D tools for situations involving significant 3D flow can seriously under-estimate both the catch efficiency and the limits of droplet impact.

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Study 2: Auxiliary Generator Inlet

- Analysis was carried out on an auxiliary generator inlet duct on a gas turbine engine.

- Aimed at providing analytical solution to compare with icing wind tunnel test results.

- Analysed conditions were as follows:
  - Altitude: 14,000 ft
  - Mach No.:   0.231
  - Static temp.:   -10.21°C
  - LWC: 0.42 g/m^3
  - Droplet diameter: 20 microns
  - Test duration: 45 minutes

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Auxiliary Generator Inlet (2)

- CFD solver (Fluent) run in fully compressible mode to second order accuracy.

- Single time-step icing solution.

- 'False' water catch introduced to model effect of D section heating.

- ICECREMO predicts ice accretion reasonably accurately.

- Lip accretion slightly over-predicted due to shielding effect of upstream accretion not being modelled.
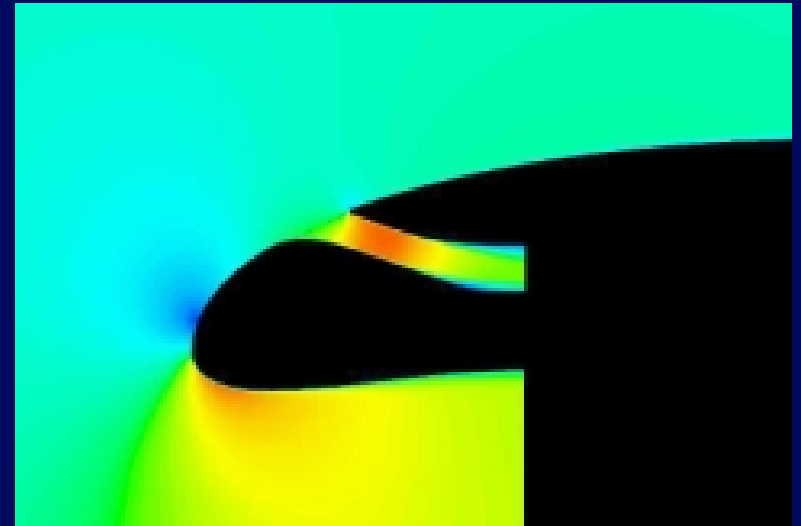
Auxiliary Generator Inlet (3)
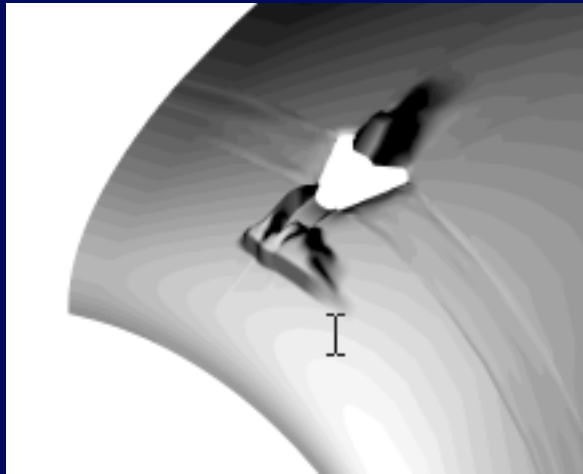
ICECREMO Prediction
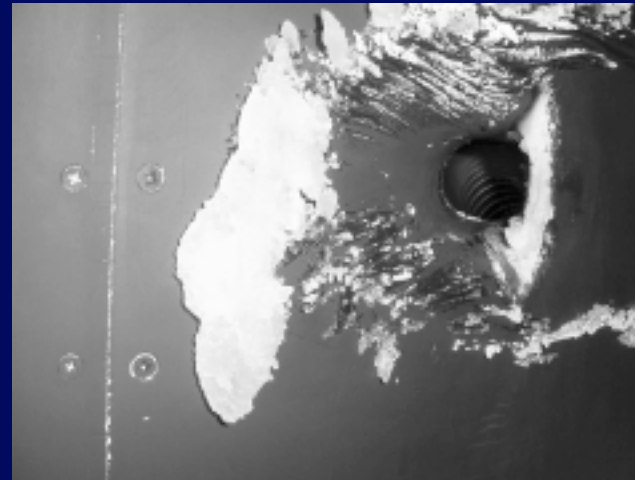
Icing tunnel
test result

Predicted duct lip
collection efficiency

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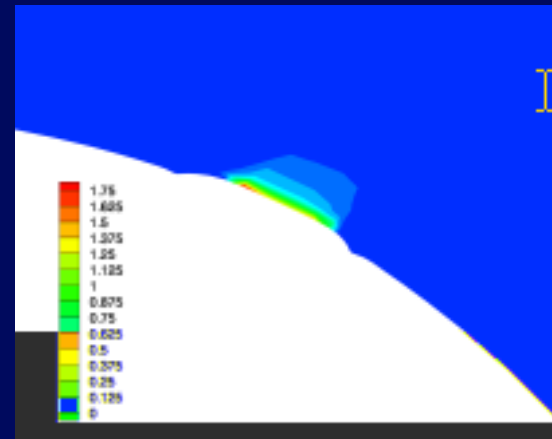
Auxiliary Generator Inlet (4)

Lessons Learned

- The use of structured grids places a limitation on ICECREMO's ability to cope with complex geometries.

- Current lack of anti-icing capability meant that 'false' catch had to be used to model nacelle lip heating.

- Presence of run-back ice shields inlet. Multi-step approach is desirable, but is highly labour intensive.

- High catch efficiency on inlet duct lip due to high mass flow through duct.

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Study 3: BAC 1-11 Sensor Fairings

- QinetiQ owned BAC 1-11 avionics flight test aircraft fitted with two external sensor arrays: a 'canoe' fairing lying on the upper starboard side of the fuselage, and a 'top-hat' fairing on the underside of the fuselage.

- Analysis aimed to determine maximum severity of ice accretion on the two components, with a view to advising an icing clearance.

- Concern that ice shed could endanger engines.

- Droplet size and cloud LWC varied in accordance with FAR-25 Appendix C.

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BAC 1-11 Sensor Fairings (2)

- Initial calculations made using ICECREMO.

- Results presented from an alternative 3D trajectory code.

- Proprietary panel method used to perform trajectory analysis, based upon open source code for droplet trajectories.

- Results obtained for both cruise and climb cases.

- Significant translational and rotational movement of droplets found. Start positions of droplets therefore very important to get correct impact information.

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BAC 1-11 Sensor Fairings (3)

BAC 1-11 Sensor Fairings (4)

<u>Lessons Learned</u>

- Highlighted need for great care in initial stages of analysis (grid definition, trajectory starting points).

- 3D nature of the flow causes significant rotational movement of the droplet trajectories.

- Near off-body velocities may not be adequately predicted by panel methods.

- Good visualisation tools are essential for complex 3D analysis.

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Conclusions

- Investigations have been conducted on three test cases, using a 3D analysis for droplet trajectories and ice accretion.

- Overall, the ICECREMO code has shown itself to be a useful tool for ice accretion analysis on complex geometries.

- 2D analysis of components with significant 3D flow can produce substantial under-prediction of catch efficiency and impact limits.

- Significant shielding can occur when analysing complex geometries, which can considerably reduce the overall amount of ice formation and lead to localised ice thickness increases.

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Conclusions (2)

- Use of a structured grid requires great care in the grid design, especially in areas of large velocity gradient.

- Large ice formations require a multi-step approach, which is not well suited to the requirement for structured grids.

- The definition of trajectory starting points in the freestream must be carefully made.

- Trajectories can undergo significant out-of-plane translational and rotational movement.

- Improvements noted are planned under the ICECREMO2 development which commenced January 2003.

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Any Questions?

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